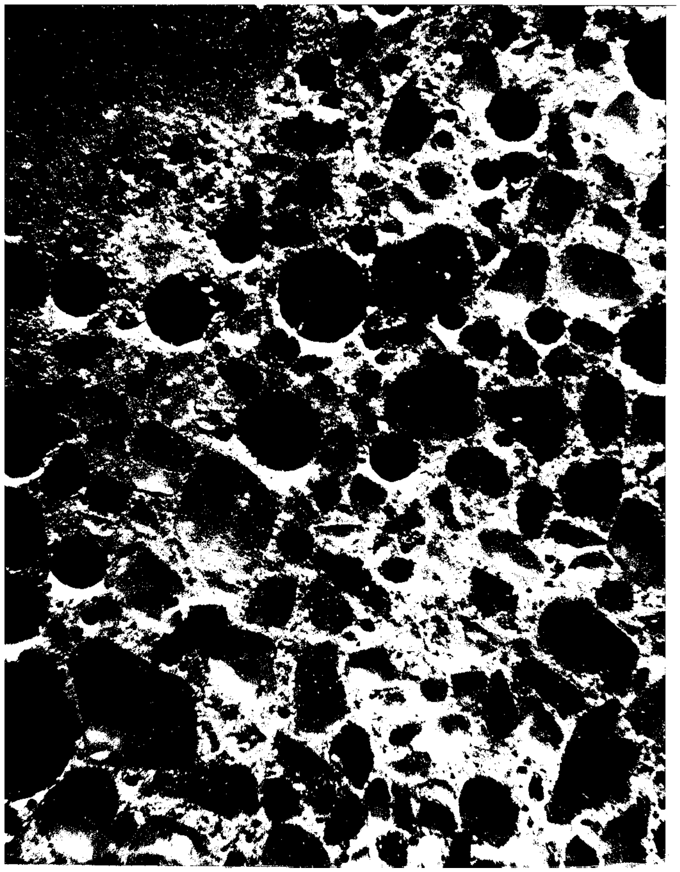
# REMR TECHNICAL NOTE CS-ES-1.7

# PETROGRAPHIC EXAMINATION OF DISTRESSED CONCRETE



Air-entrained concrete, magnification 25X

PURPOSE: To introduce field personnel to investigative techniques that determine cause of concrete distress.

APPLICATION: The science of concrete petrography can be used to determine (1) the current condition of concrete, (2) the causes of distress to concrete, (3) whether the deterioration will continue, and (4) if deterioration is expected to continue, the amount of damage to be expected. This information can be used to direct a course of action that will restore the concrete structure to the desired level of structural and functional integrity.

BACKGROUND: Classically, petrography is the systematic identification and classification of rocks and minerals according to hardness, specific gravities, and other visual and physical properties. The term "concrete petrography" implies using geological techniques to classify materials used in the production of portland-cement concrete and to investigate distressed concrete to identify the causes of distress. In a broad sense, concrete petrography is providing a visual and a physical (strength, density, air content, etc.) description of concrete.

Causes of distressed concrete can be put into three broad categories: 1) deficiencies in the design, 2) problems in the construction, and 3) inadequacies in the materials. Petrography can be used to identify both construction caused and material-caused distress. Petrography cannot be used to determine deficiencies in the design aspects of a concrete structure except when the investigations show that the probable cause of the deterioration is not related to either the construction or the materials, inferring that design should be evaluated as a probable cause.

PROCEDURE:

a. Field observations. Recognition that distress has occurred or is occurring in a concrete or that there is a deficiency in the concrete that is not normal or expected is the first step of the petrographic examination. Detailed observations and information gathered from the field provide the basis for the laboratory studies. Therefore, field observations must be conveyed accurately to the laboratory petrographer. Often a telephone conversation from the field observer to the laboratory petrographer is sufficient. If a project is extensive and the cause of the distress is not apparent, a site visit by the petrographer may be warranted.

   All available information and documentation concerning the project are potentially useful for the investigation. Construction records, mixture proportion sheets, inspection records, contract documentation, materials certification sheets, mill certificates, construction photographs, etc. may lead to some theory concerning the cause of the concrete distress. The petrographic examination can be used to verify or reject the theory.

b. Sampling*. Sampling for petrographic examination can be as simple as picking up a concrete fragment and sending it to the petrography laboratory for a cursory examination. This procedure normally will help the petrographer to determine the scope of the investigation that will be needed. In general, a more extensive sampling program will be dictated by the scope of the investigation. Many investigations require a drilling program to determine the overall quality of the concrete and the extent of the distress.

   Whenever possible, it is desirable to obtain samples from areas of concrete where distress has not occurred (good quality concrete) as well as from areas where distress is evident. A sample, or samples, of good quality concrete is needed so the petrographer can establish a baseline for comparing the distressed concrete.

   When the concrete structure is a pavement slab, beams are sometimes extracted for petrographic examination. However, samples usually consist of cores taken from the concrete to be examined. The size of the cores is

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• Guidance for sampling is given in "Standard Practice for Examination and Sampling of Hardened Concrete in Constructions" CRD-C 26, ASTM C 823. It is suggested that if possible litigation or contract dispute occur, this standard practice be followed.

largely dependent on the maximum size of coarse aggregate used in the concrete and the quality or condition of the concrete being sampled. Normally, the larger the aggregate and the poorer the quality of the concrete, thelarger the core required to obtain adequate samples. When the cores are to be used to determine the compressive strength of the concrete, the recommended minimum nominal diameter of the core is three times the diameter of the maximum size aggregate. Where the concrete is of good quality and small aggregates (<3/4 in.) are used, NX- (2-1/8-in.) diameter cores may be adequate.

c. Information obtained from petrographic examination. A petrographic examination can perform the following:

- Evaluate

  Mixture proportioning
  Effectiveness of mixing
  Consolidation
  Curing/carbonation
  Water content
  Degree of maturity (cement hydration)
  Bonding in multi-course applications
  Discoloration or staining

- Detect

  Segregation caused by over vibration
  Coarse-ground cement
  Partially hydrated or old cement (lumpy)
  Retempering
  Fly ash
  Granulated blast furnace slag
  Ground limestone, etc., as cement extender
  Cement alkali-aggregate reactions
  Masonry cement
  Freezing of plastic concrete
  Freeze-thaw distress of concrete matrix
  Distress caused by unsound aggregates
  Sulfate attack
  Contaminants
  Adverse galvanic action

- Determine

  Air content in hardened concrete
  Parameters of the concrete air-void system

- Identify

  Rock and mineral composition of aggregates
  Texture of aggregates

- Supplement

  Chemical analysis

Some things that a petrographic examination cannot do:

- Determine

  The type of portland cement used
  Quantitative amounts of fly ash or granulated blast furnace slag
  Type of air-entraining agent used

d. Petrographic examination. A variety of different tools are available for a petrographical examination and analysis. It would be impractical to describe all of the tests that can be conducted and the type information gained by each. In the following paragraphs several sample investigations are described to illustrate the potential use of petrography and the type of information that is needed for each analysis.

Example #1. Determine the mixture proportion of the hardened concrete. This investigation can be conducted to determine whether the buyer received the concrete specified in the purchase agreement. The simplest method to approach this problem is to use information from the field records and perform a modal analysis of the concrete.

General guidance for the modal analysis is given by the modified-point-count method described in "Standard Practice for Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete" CRD-C 42 (ASTM C 457). At the same time the point counting for the air content is being done, categories of coarse aggregates and fine aggregates can be distinguished by size as they are identified in the mixture proportion sheet found in the field documentation. This separation is usually the #4 sieve separation (4.75 mm).

Particles larger than nominal 4.75 mm are considered coarse aggregate, and particles smaller than nominal 4.75 mm are considered fine aggregate.

The frequency with which each component (coarse aggregate, fine aggregate, paste, or void) is intersected by regularly spaced lines on the sample is related to the volume of the ingredients making up the concrete. The mixture proportion is then calculated as follows:

Information provided by modal analysis:

| Component | Frequency |
|---|---|
| Coarse aggregate (CA) | CA% |
| Fine aggregate (FA) | FA% |
| Paste (P) | P% |
| Air content (A) | A% |
| Total | 100% |

Field Information needed:

CA specific gravity $SPG_{CA}$
FA specific gravity $SPG_{FA}$
Cement specific gravity $SPG_{C}$
Water/Cement ratio W/C

The mixture proportion is calculated for a cubic yard of concrete as follows:

$$CA = CA\% \times 27\ ft^3/yd^3 \times SPG_{CA} \times 62.4\ lb/ft^3$$
$$FA = FA\% \times 27\ ft^3/yd^3 \times SpG_{FA} \times 62.4\ lb/ft^3$$

$$\text{Cement content (C)} = \frac{{}^{SpG}C \times P\% \times 27\ ft^3/yd^3 \times 62.4\ lb/ft^3}{1 + W/C \times SpG_c}$$

Water content = W/C x C

In the above analysis the water-cement ratio specified in the mixture design is assumed to be correct; however, this ratio is not always correct, and an excessive amount of water used in a mixture is often the primary cause for the strength of concrete to be lower than expected or specified. Cement content and original water content can be determined as follows:

(a) The original water content of hardened concrete can be determined with a test method from Figg and Bowden (Figg 1971). The test gives acceptable results only if the concrete is sound and in no way damaged, either physically or chemically. The method is not suitable for poorly compacted concrete. The test involves the determination of (a) the water equivalent of the capillary porosity of the concrete originally filled with water at the time of setting and (b) the combined water still present in the prepared concrete sample as the cement hydrates.

(b) Cement content of hardened concrete can be determined by "Standard Method of Test for Cement Content of Hardened Portland Cement Concrete," CRD-C 30. Adding fly ash to the concrete mixture can reduce the accuracy of the test. If a sample of the fly ash is available, corrections can be made to improve the accuracy. The cement content can also be determined by the Maleic Acid Method or by determining the sulfur trioxide content. A sample of the cement must be available if determination of sulfur trioxide is used as the method.

<u>Example # 2. Detect sulfate</u> attack. Sulfate attack can take place if soluble sulfate salts are in contact with the concrete so that the sulfate ions can combine with the tricalcium aluminate in the cement to form ettringite. The formation of ettringite in the hydration of portland cement is common and does not cause any particular problems; only when the concrete is hardened and ettringite formation occurs do the expansive forces caused by the chemical reaction create a potential problem.

If examined with low power microscopy, concrete suffering from sulfate attack will show an abundance of ettringite crystals filling voids and coating fractures. Ettringite is a needle-like crystal that appears in clusters as balls or tuffs in the voids and also as acicular or silky coatings on aggregate particles or linings of voids. The expansive force caused by the chemical reaction causes disaggregation of the paste, resulting in the paste becoming highly fractured and eventually decaying to a powdery mass. Because the movement of the sulfate ions is a function of permeability, the exterior concrete is subjected most severely to the deterioration, while the interior may be intact and show no signs of damage.

While concrete in the advanced stages of deterioration caused by sulfate attack shows obvious characteristics that petrographic techniques can easily identify, sulfate attack in some cases may be difficult to identify positively with only visual techniques. Large amounts of ettringite in the paste fraction is only suggestive of the presence of sulfate attack. High ettringite content can be caused by the type of cement used; ettringite can be formed during hydration from sulfate ions in the cement itself.

A combination of chemical analysis and petrographic examination is required to positively identify sulfate attack. The source of the sulfate can be easily identified by determining the sulfate content of the adjacent soil, water that may be ponded against the concrete, run off water, or from other sources such as contamination from spills, etc.

Sulfate ion concentrations in water and soil can be determined by "Method of Test for Determination of Sulfate Ion in Soils and Water" CRD-C 403. The potential for sulfate attack exists whenever sulfate ions are present, but their presence is generally not considered a potential problem unless the concentration in the surrounding environment is greater than 0.10 percent.

Next, the amount of sulfate ions in the concrete being investigated is determined and compared to the amount permitted by the cement specifications. Field cement mill certificates or cement chemical analysis coupled with mixture proportion information can show whether there is an excess amount of sulfate ions in the deteriorated concrete.

The information obtained from the petrographic examination combined with the chemical data can then positively identify the degree to which sulfate attack contributed to the deterioration of the concrete.

<u>Example #3. Detect alkali-aggregate reaction</u>. Alkali-aggregate reaction refers to the reaction of carbonate rocks, silica rocks, or silicate rocks in the high-alkali environment of portland-cement concrete. Originally it was thought that aggregate was an innocuous component in concrete; current thought is that all aggregates are reactive in portland-cement concrete. The petrographic examination is needed to determine whether the reaction is deleterious.

Reactions from the different rock types occur in different manners, and the reaction results vary widely. Only the examination for alkali-carbonate rock reaction is considered in this example. The physical manifestations are expansion of structural elements and eventual development of irregular crack patterns.

Examination of the concrete may reveal reaction rims around the aggregate particles. If the aggregate particles are natural river gravels, reaction rims are most likely a product of weathering prior to use of the aggregate in the concrete. If the aggregate is crushed, the rims show that a reaction took place after placement of the concrete. It is not certain, however, whether the reaction is deleterious, beneficial, or innocuous. The presence of reaction rims is not necessary to have carbonate-rock reaction.

Alkali-carbonate reaction from the dedolomitization process requires the rock to be partially dolomitic. The classical, reactive carbonate rock is an impure dolomitic limestone in which the dolomite rhombohedron crystals are floating in a fine limestone matrix. The identification of brucite at the aggregate-to-paste interface or the monitoring of the changes of the magnesium content in the rock is an indication of dedolomitization and alkali-carbonate rock reaction.

Example #4. Detect contaminants. Contaminants are those materials that get into the concrete but are not part of the original mixture proportion. Inorganic materials such as aluminum metal from the beds of aluminumbedded dump trucks, dirt from the aggregate source, MgO from slag aggregates, artificial glass, gypsum, etc. and organic materials such as sugar in mixing water, animal droppings in aggregate stock piles, vegetation, wood from construction forms, etc. are some of the materials that can cause problems in the concrete.

Chloride contamination in concrete causes corrosion of the reinforcing steel. Chloride in concrete can be detected and quantitated by chemical analysis. Concrete samples for chloride content are obtained by coring the concrete or using a rotary impact drill. Chloride content at different depths in the concrete is normally determined when chloride-contaminated concrete is evaluated. General guidance for the procedure is presented in "Standard Methods for Chemical Analysis of Hydraulic Cement," CRD-C 209 (ASTM C 114) and in Federal Highway Administration report "Sampling and Testing for Chloride Ion in Concrete," FHWA-RD-77-85.

AVAILABILITY: Currently only six Corps Division Laboratories have concrete petrographic capabilities. These are the Missouri River Division Laboratory, Ohio River Division Laboratory, South Atlantic Division Laboratory, South Pacific Division Laboratory, Southwestern Division Laboratory, and the Waterways Experiment Station, Structures Laboratory.

The cost of petrographic investigation into the cause of concrete distress vary depending on the needs of the project and whether there is litigation involved in the work. Normal costs can range from $2000 to $5000 for simple investigation of a single area and the examination of approximately 3 samples. Other investigation involving larger areas with a larger number of samples and a larger scope may cost from $10,000 to more than $25,000.

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